Journal of Human Performance in Extreme Environments

Volume 12 | Issue 1 Article 2

Published online: 5-20-2015

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Recommended Citation

Tafforin, Carole (2015) "Comparison of Spatiotemporal Adaptive Indicators in Isolated and Confined Teams during the Concordia Stay, Tara Drift and Mars-500 Experiment," *Journal of Human Performance in Extreme Environments*: Vol. 12 : Iss. 1 , Article 2.
DOI: 10.7771/2327-2937.1062
Available at: https://docs.lib.purdue.edu/jhpee/vol12/iss1/2

Comparison of Spatiotemporal Adaptive Indicators in Isolated and Confined Teams during the Concordia Stay, Tara Drift and Mars-500 Experiment

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Ethospace

Abstract

The present study examines teams' behavior monitored over long-term missions in isolation and confinement to highlight human performance for future interplanetary exploration. The theoretical model refers to rules governing self-organized systems based on the heterogeneity of their own elements, i.e. cultural, gender, and individual characteristics. We used ethological method based on observations of the adaptive strategies in daily life activities through temporal indicators and spatial indicators. The protocol of observations was implemented at meal times with data collected weekly during the *Concordia stay* and *Tara drift*, and every two weeks during the *Mars-500 experiment*. Behavioral monitoring consisted of localizing and identifying team members at tables and of measuring teams' meal durations. The results showed a cyclicity of changes in meal durations during the Concordia stay, a diversity of changes in spatial positions during the Tara drift and a stability of these behavioral occurrences during the Mars-500 experiment. We discuss the ethological findings with regard to psychological contexts and indicate differences and associations among the three situations regarding group organization in the perspective of 500-day space missions.

Keywords: Adaptation, ICE (isolated and confined environment), space mission, polar regions, group dynamics

Introduction

The application of findings from extreme environments as analogs for space missions is of growing interest in the perspective of interplanetary exploration. Polar explorers (Leon, Sandal, & Larsen, 2011), space walkers (Caldwell, 2013), and Mars experimenters (Urbina & Charles, 2014) described personal accounts of their experience and performance in cold, isolation, confinement, or weightlessness conditions. Narrative descriptions have provided subjective outputs on well-being and team spirit. We propose objective behavioral observations made in these settings from an ethological viewpoint. Human ethology offers a new perspective based on observation, description, and quantification of the individual and group behavior through motor actions, facial expressions, spatial positions, and activity duration to objectively study the human–environment relationship. The present study focused on the spatial and temporal indicators of groups' adaptation in isolation and confinement. We first give the research background in a wide range of settings and then we address the hypotheses of our current research.

Background

Research in human ethology has provided useful scientific tools when applied to extreme environments such as orbital stations and space flights (Tafforin, 1994), isolation and confinement experiments (Tafforin, 2005), and polar stations in Antarctica (Tafforin, 2004). Under these extreme living and working conditions, the key question was how a team adapts to a synergy of environmental factors (physical and psychological) exacerbated with time. The future missions of "extreme teams" will be increasingly stressful, particularly from a psychosocial viewpoint. Manned interplanetary exploration (Mars, Moon) will be a fascinating challenge when men and women will have to live and work together for very long-term missions in closed space habitats (orbital station, space shuttles, transfer vehicles, interplanetary rockets) and in social isolation (solar system planets far from earth).

Human performance is the key to the efficiency of future international space crews. An efficient planetary team member will have individual adaptive capabilities as a high-accuracy mobile system complementary to robotic systems. An efficient planetary team will have a strong group cohesion with social adaptive capabilities as a self-organized microsociety.

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http://dx.doi.org/10.7771/2327-2937.1062

The behavior of the group is the common subject in the studies of group dynamics (Kanas and Caldwell, 2000; Solcovà, Gushin, Vinokhodova, & Lukavsky, 2013), group processes (Dion, 2004), group functioning (Bishop et al., 2006), group interactions (Inoue, Matsuzaki, & Ohshima, 2004; Kanas, 2004; Love & Bleacher, 2013), group relations (Berry, 2004), and group cohesion (Suedfeld, 2001; Vinokhodova & Gushin, 2014). The issues raised in these studies are related to the social rules (Johnson, Palinkas, & Boster, 2003), social support (Feichtinger & Shechenko, 2012; Palinkas, Johnson, & Boster, 2004), and social networks (Weiss & Gaud, 2004) in extreme conditions. Ethological analysis deals with this concept with the aim of emphasizing both the individual and social adaptive mechanisms leading to human performance in such environments.

According to Anzieu and Martin (1986), a group is a dynamic organization where all the forces are in equilibrium and regulated to obtain an optimal efficiency of the team's behavior. The rules of adaptive dynamics of an isolated and confined team could thus be compared to the laws governing self-organizing systems. These laws are based on the heterogeneity of their own elements (Tafforin, 2002). The goal of our study is to show how the team members with their own culture, their individual differences, and gender identity adapt their behavior to isolation and confinement environments (ICEs) over time.

The studies specifically relevant to *confined teams* concern space missions, submarine missions, and closed-tank experiments. During short-term space flights, ethological works have focused on motor-adaptive strategies expressed through new body orientations, movements, and postures (Tafforin, 1990). With long-term space missions, behavioral scientists agree that the interpersonal and group processes are of prime importance for group performance and success (Dion, 2004). Nevertheless, psychological studies are not extensive in this field. Studies on stress, anxiety, coping, controllability, and personality are relevant to selection and training, as well as in-flight and post-flight problems (Endler, 2004). Anecdotal reports from teams of the Russian orbital station (Mir) and the International Space Station (ISS) indicated some psychosocial issues. These included tension resulting from factors related to space crew heterogeneity (e.g., differences in personality, crew demographics, culture, and language background) and led to reductions in group cohesion (Kanas et al., 2006). Americans experienced fatigue and Russians experienced anxiety as part of a pattern of distress involving depression (Boyd, Kanas, Gushin, & Saylor, 2007).

Positive psychological effects of space missions are less frequently analyzed. The experience of being in space is a powerful one that is likely to have an enduring, positive impact on crewmembers' well-being (Ritsher, Ihle, & Kanas, 2005) and improve mental health (Ritsher, Kanas, Ihle, & Saylor, 2007). This salutogenic experience was particularly emphasized in Suedfeld's studies (Suedfeld, 2001, 2005; Suedfeld & Brcic, 2011; Suedfeld & Steel, 2000) by application of behavioral sciences in space. Belonging to an elite team, effective group cooperation, interdependence, mutual help, and friendship were some positive social aspects in astronaut group dynamics (Suedfeld, 2005; Suedfeld & Brcic, 2011). The space adaptation model (Tafforin, 2009) implies an optimal linkage between the team member and the social context. In our ethological studies we state that this optimization leads to a positive adaptation and the observed behavior is an indicator of this adaptation. With regard to ICEs, the International Space Station, the American Space Shuttle, the Russian rocket, and the European crew transfer vehicle are habitats with a closed configuration, reduced space, and weightless conditions. They involve small crews (three to nine astronauts) with scientific goals that are confined for the short term (several days), medium term (several weeks), or long term (more than one year).

During submarine missions, a crew is confronted with the same environmental properties: an extremely small work and living space, absence of day/night cues, no communication with the earth during silent running, and prolonged dangerous operations. This group is larger than those of space programs (20 to 120 crew members), has military goals, lacks mixed gender, and operates over a time frame ranging from brief submarine exercises (several days), to extended operational missions (several months). The rigorous and very long crew training that occurs before submarine deployments and the presence of strong hierarchical rules lead to behavioral stereotypes (Tafforin, 2006), over-learned technical responses (Eid, Johnsen, Saus, & Risberg, 2004), and optimal performance in stressful conditions (Van Wijk, 1998). Interpersonal sensitivity combined with strong achievement motivation was related to low indications of stress (Sandal, Endresen, V×rnes, & Ursin, 1999). Little information is available regarding the crews' behavior aboard. Some studies provide evaluations of submariner lifestyle factors and habits and their possible association with medical complaints (Horn, Thomas, Marino, & Hooper, 2003).

Closed-tank experiments were designed with the aim of studying these effects. Ethological investigations called ISEMSI (Isolation Study of European Manned Space Infrastructure), EXEMSI (Experimental Campaign for European Manned Space Infrastructure), HUBES (Human Behavior in Extended Spaceflight), and SFINCSS (Simulation of Flight of International Crew on Space Station) were performed to study small-group behavior in confinement chambers during European and international experimental campaigns.

In the ISEMSI (Tafforin, 1993), spatial organization within a small team composed of six members was analyzed. A global monitoring of behavioral changes was performed weekly, during a 28-day campaign. The results showed a decrease in the number of collateral activities over time, need of body mobility in a reduced space, stability of spatial positions illustrated by a dense grouping at the initial (week 1) and final (week 4) periods, and a dispersion of the team members in the mid-period (weeks 2 and 3). Frequencies of inter-individual distances were classified according to Hall's classes (Hall, 1971) which involve different spaces surrounding the individual. Results showed a decrease of intimate space (< 40 cm), with a predominance of personal space (40–120 cm) and social space (120–360 cm) within the group throughout the experiment.

In the EXEMSI (Tafforin, 1996), the individual and social behavior changes were monitored weekly during a 60-day campaign on a smaller team of four members. During the initial period (weeks 1 to 3), the spatial positions were regular with few variations in the average inter-individual distances. In the mid-period (weeks 5 and 6), a tendency to group closer was evidenced by an increase in frequency of the shortest inter-individual distances (personal and social space). The final period (weeks 7 to 9) revealed group dispersion with an increase in frequency of large inter-individual distances (public space: > 360 cm) and more frequent isolated positions.

In the HUBES experiment (Tafforin & Bichi, 1996), the individual and social behavior was observed weekly during a 135-day campaign. The results point out three periods for the smallest group of three members. The first period (first month) showed group cohesion (same postures, orientations, and positions; constant duration of collective tasks). The second period (second month) showed variations of the crew as a whole (higher frequency of collateral activities, higher meal duration). The third period (third and fourth months) showed a wide range of individual behavioral changes (motor act flow, collateral activities, directed head movements, etc.). Two critical phases were also emphasized: the initial phase (first days) and the final phase (last month) with the emergence of intimate space (< 40 cm) and an increase of the public space (> 360 cm), respectively. As a result, over the entire campaign, conditions of confinement were more and more stressful and the long-term adaptive process was not still achieved after 135 days.

In the SFINCSS experiment, comparing one group confined for 240 days and two groups for 110 days, differences in culture and attitudes toward gender were factors identified as having a major impact on the inter-group relationship (Sandal, 2004). Such experiments have demonstrated the need to extend ground simulations of the psychosocial environment encountered during very long-duration stays in ICEs. This has led to a focus on the isolation factor.

The studies specifically relevant to *isolated teams* concern trans-polar expeditions and stays in polar stations. In Antarctic polar stations, during summer campaigns (lasting two to four months) and winter-overs (lasting eight to nine months), winterers' behavior was studied in terms of adaptive answers to coping with sensory and social deprivation. In the French missions, at Dumont d'Urville polar station, typical symptoms of winter-over mental syndrome were described in three successive phases: alarm reaction, stage of resistance, and stage of exhaustion (Rivolier, Goldsmith, Lugg, & Taylor, 1988). Such reactions could lead to acute or chronic pathological manifestations (Rosnet, 1996). In Italian missions, building the new station at Dôme C, the winterers tended to become more introverted and neurotic with increases in depressive syndrome, social withdrawal, and emotional repression (Cenni et al., 2001). In American missions, at Amundsen-Scott station, there was a decline in depression and vigor and an increase in fatigue and tension-anxiety (Palinkas, Johnson, Boster, & Houseal, 1998). In Australian expeditions, at Casey, Davis, and Mawson stations, negative versus positive experiences (and vice versa) indicated that most psychological problems were transitory rather than continuous (Wood, Hysong, Lugg, & Harm, 2000). In Japanese missions, at Asuka station, subjective and cumulative fatigue symptoms were more noticeable in the older expeditioners (Ikegawa, Kimura, Makita, & Itokawa, 1998). In Chinese missions, at Great Wall station, behavioral disorders were noted in all the winterers, indicating depression, decreased attention capabilities, and decreased flexibility of the nervous system (Xue, Zhang, Yao, & Xue, 1997). In a Russian trans-Antarctic expedition, from Peninsula to Mirny station via Vostok station, mood was quite high when reaching the South Pole but slowly declined thereafter (Ursin, Etienne & Collet, 1990). Recent research on human factors at the Flashline Mars Arctic Research Station (FMARS) on Devon Island was specifically designed as part of a Mars exploration analog mission (Binsted, Kobrick, Griofa, Bishop, & Lapierre, 2010). Over a four-month simulation, males consistently used more avoidant coping while females utilized task coping and social emotional coping. Stress increased for males while decreasing for females (Bishop, Kobrick, Battler, & Binsted, 2010).

Arctic and Antarctic missions involve more mixed-gender teams with cultural identities. Including women in a wintering group seems to have positive effects on the general climate of the group by reducing men's rude behavior (Rosnet, Jurion, Cazes, & Bachelard, 2004). Women added an element of emotional support and helped other members. This pattern is not as evident in all-male groups (Leon & Sandal, 2003). On the one hand, all-male teams exhibited higher levels of competitiveness and fewer tendencies to talk about their feelings during polar missions (Leon, 2005). On the other hand, in a two-woman traverse of Antarctica, advantages of the co-equal dyad were evident in the cooperative nature of the decision making and substantial similarities in approach to solving problems (Atlis, Leon, Sandal, & Infante, 2004). All-female teams were rare until recently. In all-women expedition teams, group climate and individual functioning would be more sensitive to emotional concerns (Kahn & Leon, 2000). Regarding gender differences, social support was reported to be perceived less by female leaders and more by female followers in Antarctic expeditions (Schmidt, Wood, & Lugg, 2005). This provides evidence of the heterogeneous quality of a group to cope, regulate, and adapt for better equilibrium in isolation conditions.

Considering multicultural groups, cross-cultural comparisons have provided some findings that suggest a characteristic personality trait profile in the Antarctic expeditioner, irrespective of national origin (Musson, Sandal, Harper, & Helmreich, 2002). However, intercultural effectiveness and its relevance to multicultural crews in space were discussed in research on ICEs (Kealey, 2004). Increases in the heterogeneity of space crews' composition (cultural and gender differences) would be a risk that could negatively influence the formation of a cohesive group and that would depend on a common way of perceiving one's social environment (Gushin, Pustynnikova, & Smirnova, 2001). Few studies have been performed in Arctic and Antarctic missions with regard to international polar teams. Despite the language barriers limiting communication between team members (Ursin et al., 1990), the trans-polar expeditioners responded positively to a multicultural experience. They reported the multicultural richness of relationships within the team (Etienne, 1990). A more recent Aerocrew mission at Ny-Alesoud Arctic Base (Gourinat, Appel, & Delbart, 2010) has shown the efficiency of a transverse visiting multidisciplinary team for training and synergies with the polar scientists (glaciologists, geologists, specialists of the atmosphere). In fact, it is important to consider the individual, man or woman, in an organizational culture, different backgrounds, and with his or her own personality traits (Sarris, 2006; Palinkas & Suedfeld, 2007; Sandal, Bye, & van de Vijver, 2011).

Previous ethological studies address all of these situations. However, they dealt with adaptation of individual motor strategies for short periods and not social strategies for long periods spent in ICEs. We propose a behavioral approach to emphasize the observation of temporal and spatial variables as adaptive indicators of isolated and confined teams over extended time periods and to compare ICEs in which they are observed.

Hypotheses

The present study raises the question of living and working together with environmental constraints (separation from the external world, brief communications, reduced space, closed habitat, and monotonous workload), social specificities (a small, mixed-gender, and multicultural team), handling events relevant to a mission in extreme conditions (unexpected difficulties and emergencies, stressful tasks), and on a long-duration process. The theoretical hypotheses refer to rules governing the self-organized systems based on the heterogeneity of their own elements. An extreme team is a dynamic system progressing over time, with varied personal profiles (gender, culture, function), where all the forces are in homeostatic states (equilibrated exchanges). Our working hypotheses are as follows:

1. There are differences of temporal organization and spatial organization between the isolated and confined teams throughout the days of missions. Contributing factors are cultural, gender, and individual characteristics. We expect that the time spent together, for example the duration of meals, is different between the teams and that the team members' positions, for example the places during the meals, are grouped together among same nationality, and among women or men, and according to each individual.
2. There are associations between the ICEs on the basis of temporal–spatial indicators considering global missions. Isolation characteristics and confinement characteristics may be opposite by the temporal variable or the spatial variable but also correlated. We expect, for example, that confined team members will spend little time together with few place changes whereas isolated team members will spend longer time together but not at the same place. Team members both isolated and confined would be in an intermediate situation.

Method and Protocols

General Approach

The ethological approach is a non-invasive method based on a quantitative description of the spontaneous spatiotemporal behavior of an individual in daily life situations, tasks at work, or experimental tests. The specific goal is to explore the field of observable events that are complementary to physiological investigations and to psychological questionnaires.

Two main steps are required in the general method. The first step is to describe the actions and positions as they change over time according to environmental factors. The second step is to quantify these behavioral events in duration of occurrences or in frequency of occurrences. In this way, each event is observed, described, and quantified within its own functional and spatial frame. Such studies not only take into account the result of the behavior, that is, performance, but also the spatiotemporal patterns leading to it, that are strategies.

The present analysis applied methodological tools from ethology to three extreme environments: Concordia stay in Antarctica, Tara drift in the Arctic, and the Mars-500 experiment in multichamber facilities in Moscow.

Situations and Participants

Concordia stay

The Franco-Italian Concordia station is located at Dôme C (DC), 75°06′S and 123°21′E. The altitude is higher than

3000 m and the average temperature is −51°C. It is made of three buildings, linked by enclosed walkways. The first cylindrical building, called quiet building, houses the sleeping quarters, the laboratories, and the hospital. The second cylindrical building, called noisy building, houses the workshop, the wastewater treatment plant, the communication room, the kitchen, and the cafeteria. The third building is made up of eleven container-sized modules and houses the electric power plant, the boiler room, and a second workshop.

After the summer campaign, the wintering started on 9 February 2006 and ended on 4 November 2006 with the landing of the first Twin Otter plane. We consider the isolation to have been broken on 9 November 2006 with the arrival of summer personnel.

The participants observed for the study were the winterers. In DC mission 2 (DC2), the winter team was composed of six French team members and four Italian team members, of whom two were women (one Italian and one French) and eight were men ($n=10$). It was made up of four technicians for the station maintenance, four scientists for the research programs, a cook, and a medical doctor who also was the expedition chief. The team members were between 23 and 59 years of age, with an average age of 37 years.

Tara drift

The Tara expedition is a 507-day polar drift of the Tara schooner in the Arctic Ocean from 3 September 2006 to 21 January 2008. It was embedded in the pack-ice from a northeastern latitude (79.53°N, 143.17°E), crossed 5,200 km, and was released from the ice at a northwestern latitude (74.08°N, 100.04°W). It is of 36 m in length and 10 m in depth with 14 berths, a quarterdeck, a cooking area, a communication area, a technical area, storage areas, and a navigation area on the upper deck. In the summer period, the temperature could reach +9°C and in winter during the polar night, the coldest temperature could reach −41°C. In collaboration with the European research program Damocles, scientists aboard Tara have collected data in the atmosphere up to an altitude of 2,000 m and in the Arctic Ocean to a depth of more than 4,000 m.

After a first wintering with summer periods (September 2006 to April 2007), relieving teams ($n=10$) boarded the Tara schooner for the second summer period and winter-over (May 2007 to January 2008).

The participants observed for the study were composed of a summer team with two women (French) and 8 men (five French, one New Zealander, one Estonian, one Norwegian) then a winter team (three members being replaced) was composed of three women (two French, one American) and seven men (four French, one New Zealander, one Russian, one Norwegian). The team members were made up of a captain, a chief engineer, scientists, a cook, a journalist, and an artist. They were between 23 and 52 years of age, with an average age of 33 years.

Mars-500 experiment

The Mars-500 program is a 520-day experimental paradigm that simulated different phases of a mission to Mars: a 250-day interplanetary flight from Earth to Mars, a 30-day orbital stay that included the Mars landing and a 240-day interplanetary flight from Mars to Earth. It began on 3 June 2010 and ended on 4 November 2011. It is a joint experiment of the European Space Agency and the Space Agency of the Russian Academy of Science. The multichamber facilities were located at the Institute of BioMedical Problems (IBMP) in Moscow. They were composed of four hermetically sealed, interconnected modules: the habitable module, the medical module, the storage module, and the Mars landing module. The total volume of the modules was 550 m^3 and the volume of the Martian surface was 1200 m^3. In the habitable module, there were a living room, a dining room, six private cabins with berth and a single toilet/shower. The artificial atmospheric environment was set at a normal barometric pressure.

A 20-minute communication delay was simulated throughout the experiment and unexpected tests of loss of communication were simulated as periods of high autonomy. On 1 February 2011, the team entered a circular orbit around Mars. It was separated during 15 days between the orbit crew ($n=3$) and the Mars crew ($n=3$). On 2 March 2011, the crew departed from Mars for the return trip on Earth.

The participants composed an international crew with three Russians, two Europeans, and one Chinese ($n=6$). Their functions during the experiment were one commander, two physicians, and three engineers. The team members were all males, aged between 26 and 38 years, with an average age of 32 years.

All the participants in each situation gave their consent to participate in the study.

Observation Sessions

During Concordia stay, observation sessions were made in the noisy building (the dining room) and were conducted by the wintering medical doctor on quantitative temporal data and spatial data on all the team members. A drawing of the location of the main table and of the numbered seats in the room chosen for the meals was made beforehand. Each session consisted of completing a table in a Microsoft Excel file with the number of the seat (1 to 10) allocated to the named subject per day. Meal duration information was noted as well. The observation sessions included digital pictures and video scanning as backup and data control, and were performed weekly over eight winter months. The protocol covered 38 points of observation from day 1 to day

260. The observation day was every Thursday and the chosen meal time was dinner in the evening.

During Tara drift, observation sessions were made in the quarterdeck (the dining area) and were conducted by the same medical doctor used during the Concordia stay, and following the same protocol. The quantitative temporal data and spatial data were collected on all the team members, every Thursday at dinner time. The observation sessions included digital pictures and video recordings as backup and for additional analyses.

During the Mars-500 experiment, the frequency of observation was twice a month and the sessions were made in the habitat module (the dining room). The full protocol covered 37 points of observation from day 19 to day 513. The first period, one-way to Mars, was chosen for harmonizing the data with those of the Concordia stay and Tara drift. It corresponds to 18 points of observation from day 19 to day 257. Video recordings from inside cameras allocated for surveillance coverage (no audio) were activated by the outside personnel at the experiment control center. The recording day was every Thursday and the studied meal time was breakfast in the morning (data collection during dinner time was not authorized).

Specific Tools

At the laboratory in France, frequent briefing reports were checked. Efficient data collection procedures, both in extreme environments and in extended periods of time, require that the ethological researcher keeps contact with the ground observer or the video technician in order to keep the protocol rigorous and to gather as much data as possible. This was facilitated with communications via electronic mail in the three situations.

The observational data processing issued from the Microsoft Excel spreadsheet files mainly contained cartographic information and collective time information. The observational data issued from the video files were processed in the same way. An assessment of the duration when subjects were sitting around the table was implemented for each day of observation. These are the temporal indicators. A mapping of the position of each subject sitting at the table was implemented for each day of observation. These are the spatial indicators. The team members' attendance was taken into account as a result. Subject numbers, meal durations, and spatial positions were carefully measured.

Statistical Tests

We calculated means, median values, and moving means of duration (min). The standard deviation (SD) is the amount of variation around the mean and gives the significance of the basic values. The median is the value separating the higher half of observations and gives a true value of the variable that is being measured. The moving mean is a series of averages of subsets of the full data over the days. We chose non-parametric descriptive statistics to give tendencies.

We made a principal component analysis (PCA) to correlate the spatial variable and the temporal variable between the three situations of observation and to assess the loading of isolation and confinement factors. We chose the PCA because it is a statistical procedure that supports the differences and associations observed on the whole data. It uses the Karl Pearson test whose results are evaluated through the chi-squared distribution between the observed data and the theoretical data, that are equal frequencies.

Results

Temporal Indicators

Living and working in an ICE is punctuated by social activities and individual tasks. The meals are periodic meetings of the team members in the collective areas of the habitats. The collective attendance was evaluated by the percentage of team members who were present and sat at the meal table for each situation of observation. When meals were served at an imposed time the attendance was very high ($> 80\%$). As a result, we chose dinner within the time slot 7:00–8:00 p.m. for the Concordia stay and Tara drift; we chose breakfast within the time slot 9:00–10:00 a.m. for the Mars-500 experiment. Day-to-day meals give the possibility to spent time together, as a group. Meal duration is thus a temporal indicator of the isolated and confined group's adaptive process. This was evaluated by the arrival time (hour:minutes) of the first team member at the table and the departure time of the last team member.

During the Concordia stay (Figure 1), the mean time of meal durations was 71 min with high variation, and a median value of 34 min. The moving mean presents cyclic variations over the days with increasing peaks at day 29, day 78, day 134 and day 176. These regular temporal intervals reflect cyclicity in the changes of meal durations. We have to consider that mid-winter, at about day 134, was a significant event and that the evening time spent together lasted until the morning (660 min). This is a way to identify the date of the longest polar night that is the most remote period from both the first day and the last day of the mission. Such a temporal indicator could reveal an adaptive strategy to expected events or particular conditions. The results show a cyclic organization of the isolated and confined team during the Concordia stay.

During the Tara drift (Figure 2), the mean of meal durations was 42 min with a smaller SD (10 min), and a median value of 42 min. This collective time is globally higher than during Concordia stay. We did not observe major changes at about day 64, that is the longest polar day, and at about day 148, that is the exchange period between the

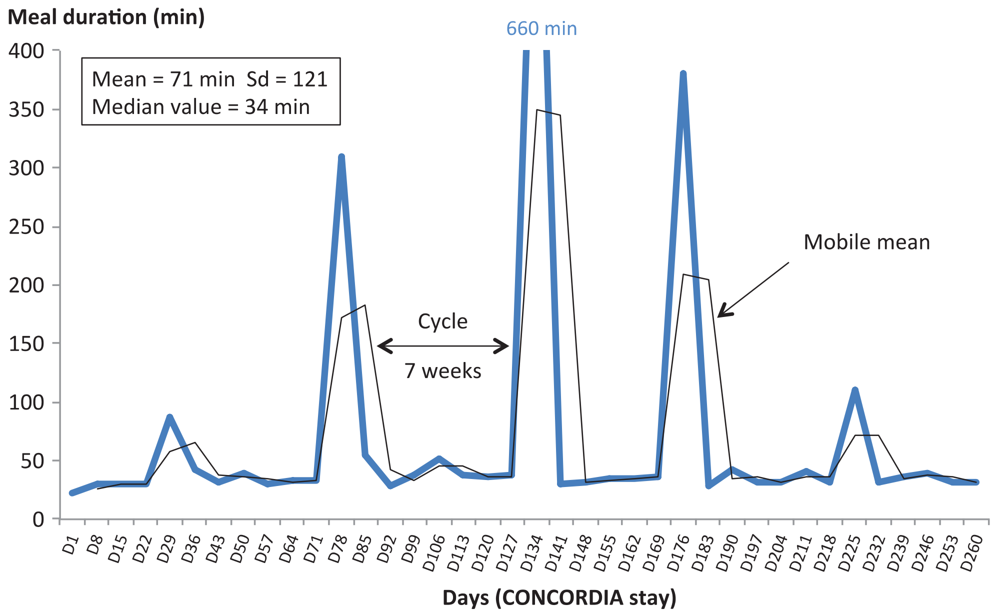

Figure 1. Team's dinnertime over days during the Concordia stay.

summer team and winter team. Such a temporal indicator could reveal an adaptive strategy in maintaining group cohesion despite the contextual conditions. The moving mean presents variation over days but without obvious peaks. We did not observe cyclicity in the changes of meal durations in comparison with the Concordia stay. The results show a different temporal organization between the isolated and confined teams during the Concordia stay and Tara drift over long-term missions.

During the Mars-500 experiment (Figure 3), the mean of meal durations was 29 min (SD=7 min), and a median value of 29 min. This is the lower collective time in comparison with the Concordia stay and Tara drift. The moving mean reveals a continuous line with the lowest level of variation over days. We did not observe changes at about day 131, the most remote period from the day of leaving the Earth and from the day of reaching Mars. In addition, we did not observe cyclicity in the changes of meal durations in comparison with the Concordia stay. However, we did observe the same dynamic profile as occurred during the Tara drift. Such a temporal indicator could reveal an adaptive strategy in maintaining group

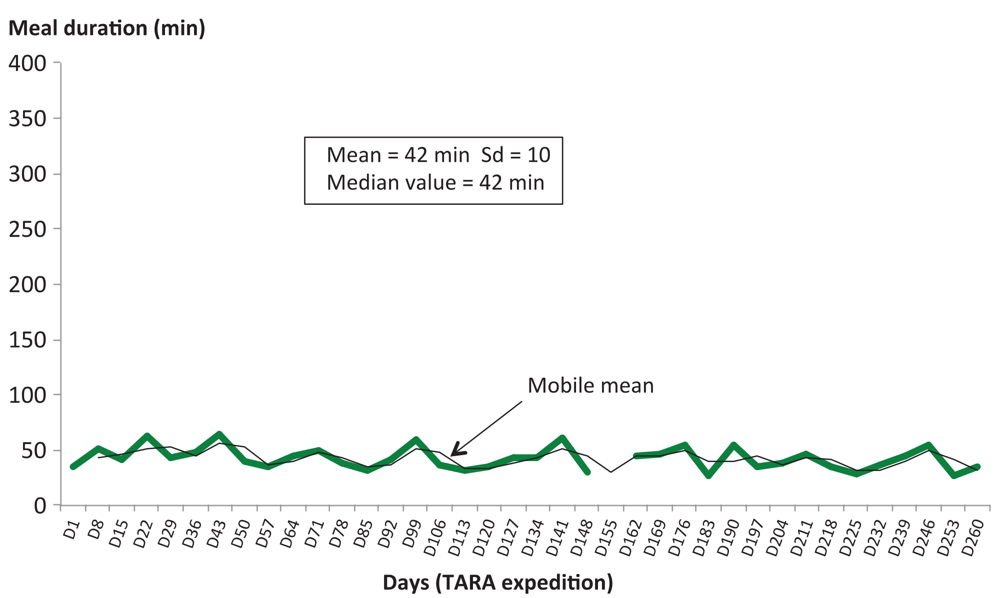

Figure 2. Team's dinnertime over days during the Tara drift.

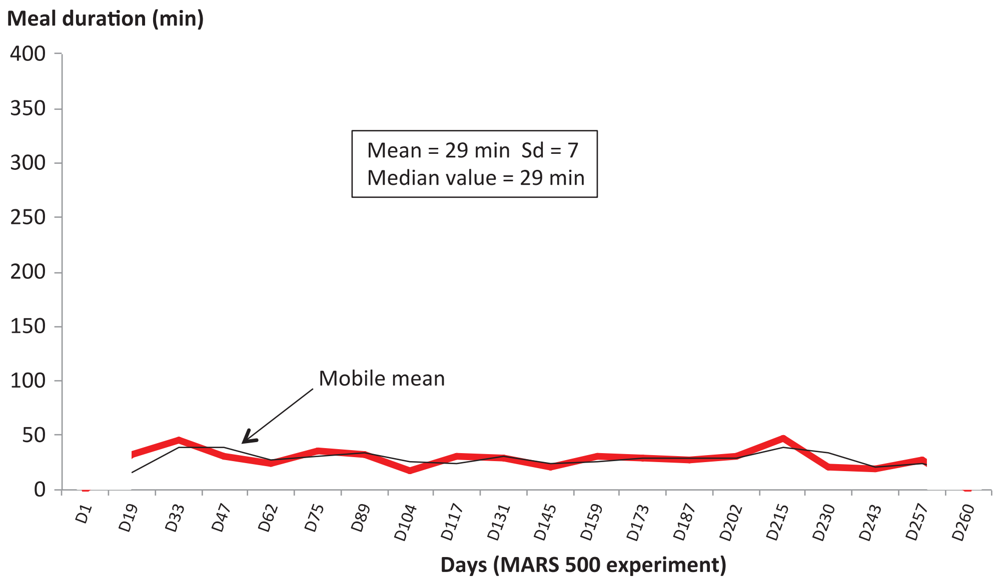

Figure 3. Team's dinnertime over days during the Mars-500 experiment.

cohesion over long-term missions. The results show a similar temporal organization of the isolated and confined teams during the Tara drift and Mars-500 experiment.

Spatial Indicators

In ICEs, the space available for social activities is a meeting point and a team's landmark. When considering all the situations, the team members have their own choice of a place at the collective table during meal time. Place preference corresponds to the prime choice of position. This is a spatial indicator of the isolated and confined group's adaptive process. We evaluated this indicator by frequency. An emphasis was placed on individual, gender, and cultural characteristics.

During the Concordia stay, the team members' position is described by the place number from 1 to 10 (Figure 4). A colored scattergram shows repetitive placing over time, from day 1 to day 260. Each square with an assigned color is a subject position (C1 to C10) per day (Figure 5). We observed continuous periods of positioning at the same place according to each individual. Subject C3, subject C4 and subject C9 have strong place preferences throughout the mission. This is particularly emphasized when distinguishing Italian subjects (green squares) and French subjects (blue squares). A central place (place 9) is always occupied by a French team member (continuous blue line). The front place (place 4) has the same status. These results combined with the left side places show an area of French place preferences. On the other side, Italian place preferences appear, delineating an Italian area. We observed that women (pink square) are not adjacent compared to the men (grey square) and show some continuous periods with no change. Such a temporal indicator would reveal an adaptive strategy in the places occupied. The results show that the spatial organization of isolated and confined teams is performed according to individual, gender, and cultural characteristics.

During the Tara drift, the team members' position is also described by the place number from 1 to 10 (Figure 6). The colored scattergram shows alternate placing over time, from day 1 to day 260. Each square with an assigned color represents a different subject position (T1 to T10/T4) per day (Figure 7). We did not observe continuous periods of positioning at the same place in comparison with the Concordia stay; each subject changed places throughout the mission. This is also emphasized when distinguishing the subjects from America, France, New Zealand, Norway, Estonia, and Russia (shown by different colored squares). We observed cultural diversity in the places occupied and not strong team member grouping. We also observed that women (pink square) were not adjacent but more frequently changed place compared to women during the Concordia

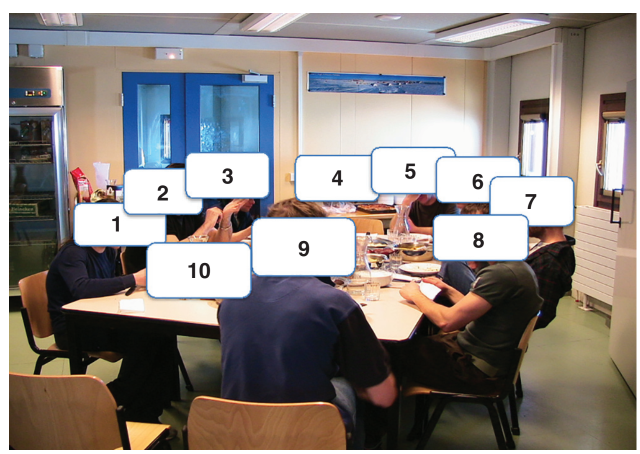

Figure 4. Places at table (#1 to #10) in the dining room of Concordia station (image courtesy of M. L. Pham Minh/Ethospace, 2006).

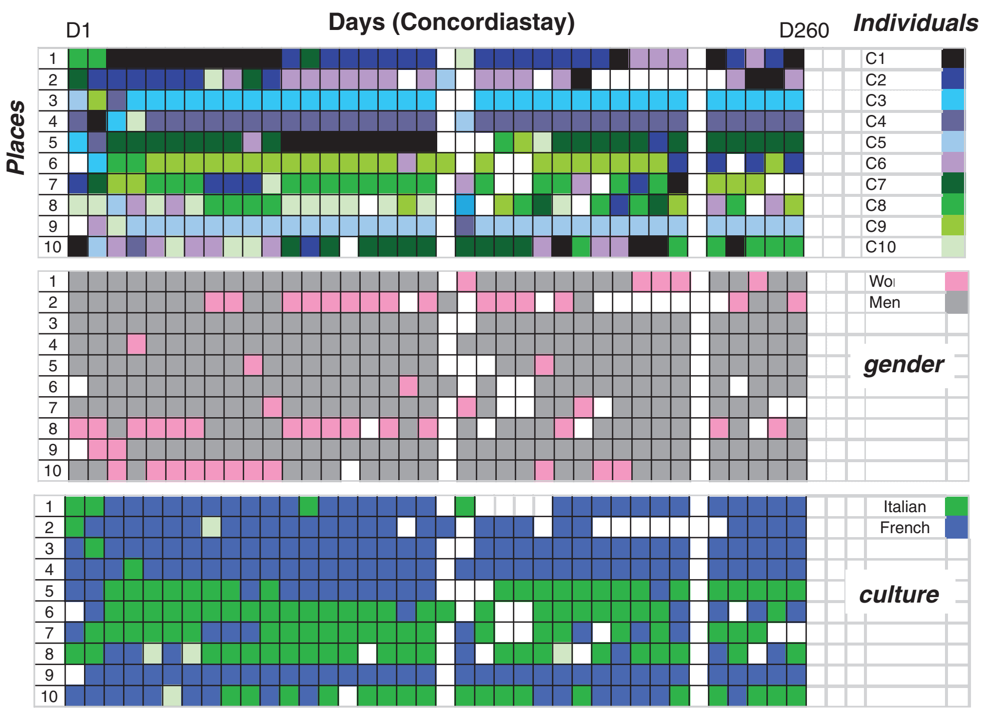

Figure 5. Team members' positions (places #1 to #10) according to individuals (top scattergram), gender (middle scattergram), and culture (bottom scattergram) at dinnertime from day 1 to day 260 (squares) during the Concordia stay (scattergrams: columns = places; lines = days; colors = subjects).

stay. Such a temporal indicator would reveal an adaptive strategy in the places occupied. The results show a different temporal organization between the isolated and confined teams during the Concordia stay and Tara drift with individual differences, gender, and cultural variations.

During the Mars-500 experiment, the team members' positions are described by a place number from 1 to 6 (Figure 8). The colored scattergram shows strong repetitive placing over time, from day 19 to day 257. Each square with an assigned color designates a subject position (M1 to M6) per day (Figure 9). We observed continuous positioning at the same place according to each individual. The team members have strict place preferences throughout the mission. This is also emphasized when distinguishing among European, Chinese, and Russian subjects. On one side, Russian place preferences appear (place 4, place 5, and place 6), delineating a Russian area. On the other side, we observed a grouping of non-Russian team members. Within this sub-group, European subjects (purple squares) were not adjacent, but nevertheless did not change place at all. This team was not a mixed-gender group. Such a temporal indicator would reveal an adaptive strategy in the places occupied with no change, thus reinforcing group cohesion. The results show different spatial organization between the isolated and confined teams during the Concordia stay, Tara drift and Mars-500 experiment.

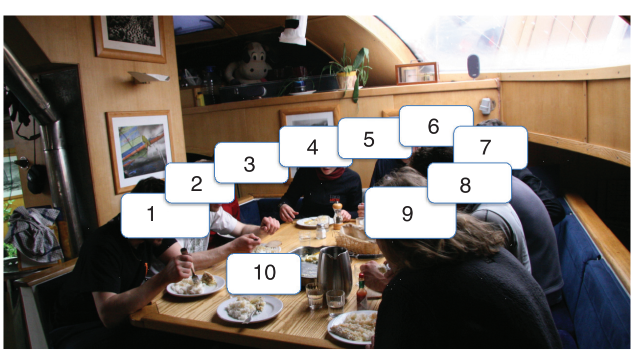

Figure 6. Places at table (#1 to #10) in the Tara drift (image courtesy of M. L. Pham Minh/Ethospace, 2007).

Principal Component Analysis

Time and space would have to be combined for building optimal behavioral strategies in ICEs. We proceeded to a PCA to further investigate associations between the Concordia stay, Tara drift and Mars-500 experiment on the basis of spatiotemporal indicators. PCA uses orthogonal transformation to convert observations into possibly correlated variables. In our analysis, the temporal variable (T) corresponds to the meal durations (min) and the spatial variable (S) corresponds to the place changes (%) assessed over 260 days and correlated for the three situations (Concordia-T, Concordia-S, Tara-T, Tara-S, Mars-T, and Mars-S). In the sphericity test, the total significant threshold is $p = 0.05$ for a chi-squared $X^2 = 13.447$ and a degree of freedom $k = 15$. The Pearson test (Table 1) shows correlation coefficients (R) between the two variables (two-tailed) with low significances ($0.05 < p < 0.1$).

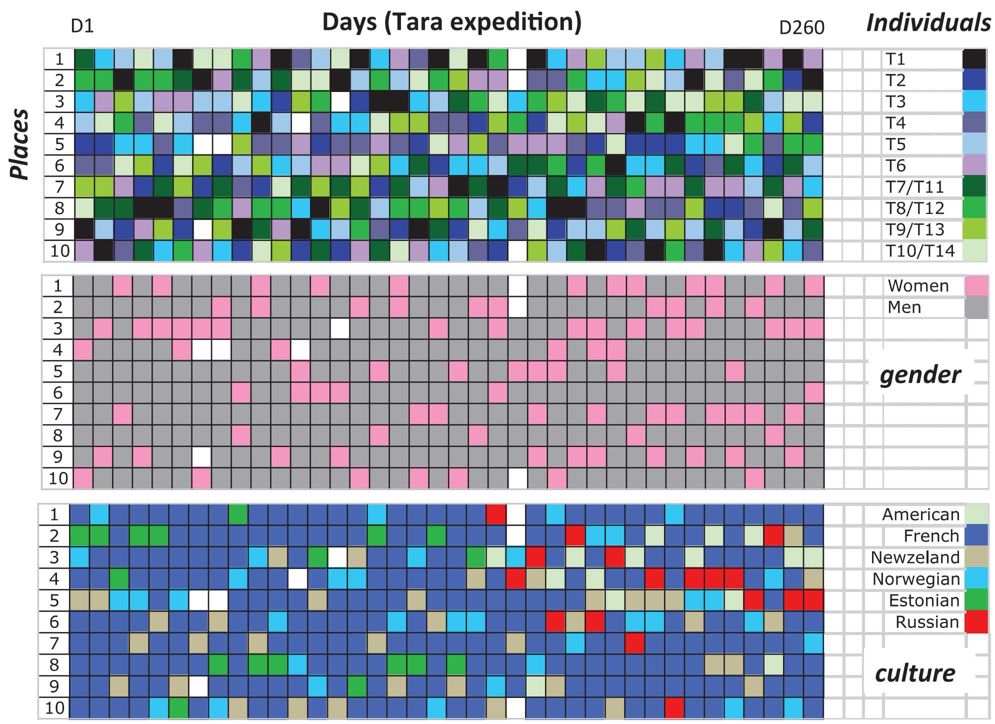

Figure 7. Team members' positions (places #1 to #10) according to individuals (top scattergram), gender (middle scattergram), and culture (bottom scattergram) at dinnertime from day 1 to day 260 (squares) during the Tara drift (scattergrams: columns = places; lines = days; colors = subjects).

We did not detect a salient factor about the axis F1 (Table 2) but two axes F2 and F3 have stronger contributions of variables (in bold) within the circle of the PCA (Figure 10). First, they distinguish the Mars-500 experiment (lower sphere) to the Concordia stay (right sphere) and Tara drift (left sphere) with a loading of 39%. These results show that the isolated and confined teams in each situation have different temporal and spatial organizations supporting our first hypothesis. Furthermore, this confirms the differences initially observed throughout the days of missions with the influence of cultural, gender, and individual characteristics of the team members.

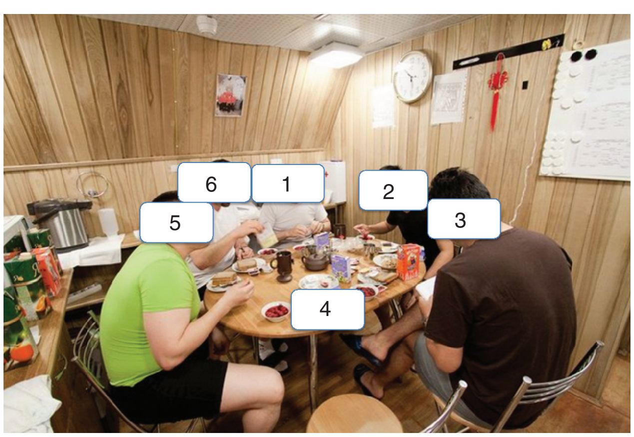

Figure 8. Places at table (#1 to #6) in the kitchen of Mars-500 habitable module (image courtesy of A. Smoolevskiy/IBMP, 2014).

Second, the Concordia stay presents a significant temporal variable (nearest to the circle) and is opposite to the spatial variable of Mars-500. Projections on the F3 axis (red axis) indicate that the spatial variable of the Concordia stay is situated between the Tara drift and Mars-500 experiment. In the same way, projections on the F2 axis (blue axis) indicate that the temporal variable of the Concordia stay is situated between the Tara drift and Mars-500 experiment. The results indicate associations between these extreme environments on the basis of temporal and spatial indicators, supporting our second hypothesis. The Mars-500 experiment was characterized by its strong confinement factor versus the Tara drift characterized by its isolation factor. The Concordia stay involved a team both isolated and confined, and it is intermediate to the two opposite environments.

Discussion and Conclusion

Human adaptation that underlies human performance is a complex phenomenon. In extreme environments, it depends on personal, group, and contextual variables and it is a dynamic process. The literature review in extreme settings showed behavioral disorders, loss of group cohesion, and occurrence of depression in team members. These settings may have a negative impact on performance. In contrast, the Concordia stay, Tara drift, and Mars-500 experiment were exceptional paradigms that allowed us to describe teams' performance in ICEs in a positive way. In accordance with

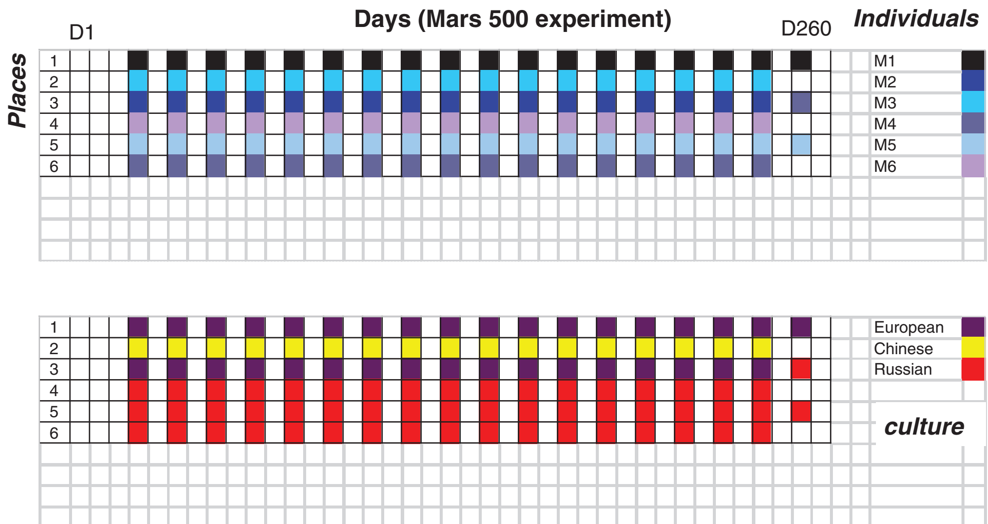

Figure 9. Team members' positions (places #1 to #6) according to individuals (top scattergram) and culture (bottom scattergram) at dinnertime from day 19 to day 257 (squares) during the Mars-500 experiment (scattergrams: columns = places; lines = days; colors = subjects).

the working hypotheses, this description led us to distinguish the isolated and confined teams throughout the days of missions, and to correlate the environmental characteristics considering global missions.

First, the behavioral indicators monitored in the team members provide an overview of variations in the adaptive process. Variations of time indicated by the meal duration changes during the Concordia stay and variations of position indicated by the place changes during the Tara drift are objective events, underlying isolated and confined teams' strategies. These strategies show what occurred. Our interpretation is why they occurred. In previous results stated in the research background, behavioral changes over time and among team members occurred because of mood variations (stress, anxiety, tension). The present results rather match optimal comfort feeling and how the changes were used. We could explain the cyclicity of changes in meal durations as a temporal organization to vary the rhythm of collective time over extended time periods. Also, we could explain the diversity of changes in spatial positions as a spatial organization to cope with the monotony of daily life activities in isolation and confinement. These spatiotemporal indicators are objective events that may be used to anticipate changes in well-being or team spirit over time.

Observational findings are the basis of the methodological tools used in ethology. Nevertheless, as is argued in social and environmental psychology literature, the context in which the behavior is observed has to be considered for appropriate interpretation. An environmental psychology study (Weiss, Feliot-Rippeault, & Gaud, 2007) of place use and setting preferences also evaluated in the Concordia station enlarged the analysis to four kinds of places (i.e., main hall, working area, bedrooms, outside) and to seven categories of activities (i.e., resting, working, playing, leisure, contemplation, solitary activities, social activities). The perception of the team members seemed to indicate variations in location according to occupation (i.e., scientists or technicians) and age groups. Our results on place preferences according to individual, gender, and culture support that differences in behavior occurred. Psychological analyses with subjective data from daily questionnaires and ethological analyses with objective data from daily life observations combine to show that group

Table 1
Pearson test in the PCA.

R	Concordia-T	Tara-T	Mars-T	Concordia-S	Tara-S	Mars-S
Concordia-Time	*1.0*	0.078	0.026	**0.345**	0.062	−0.109
Tara-Time	0.078	*1.0*	0.045	**0.420**	**0.270**	**0.228**
Mars-500-Time	0.026	0.045	*1.0*	**0.276**	−0.157	−0.005
Concordia-Space	**0.345**	**0.420**	**0.276**	*1.0*	0.093	**0.430**
Tara-Space	0.062	0.270	−0.157	0.093	*1.0*	0.195
Mars-500-Space	−0.109	**0.228**	−0.005	**0.430**	0.195	*1.0*

Note. Bold: significant correlation level, $0.05 < p < 0.1$; italic: similar variables.

Note. Bold: high contribution.

Table 2
Contributions of variables in the PCA.

%	F1	F2	F3
Concordia-Time	5.989	12.515	57.951
Tara-Time	25.584	2.304	0.059
Mars-500-Time	2.652	40.379	13.171
Concordia-Space	37.346	7.314	0.043
Tara-Space	8.643	30.738	7.300
Mars-500-Space	19.785	6.750	21.477

organization benefits from differences in personal characteristics to adapt to isolation and confinement.

Second, the spatiotemporal indicators monitored in the team members give an overview of continuous adaptive periods. This is particularly visible during the Mars-500 experiment. Reduced variation of meal durations and strong repetitive placing are features of the team's behavior in conditions of strict confinement, high autonomy, and extended time periods. The continuity of behavioral manifestations could be interpreted as if team members were maintaining a reference of group organization, for keeping cues from the beginning to the end of the experiment with stable behavior, whereas the psychological state and the physical state change. A psycho-physiological study (Basner et al., 2014) of stress reactions was implemented during the Mars-500 experiment. The results showed substantial inter-individual differences. Two team members who had the highest ratings of stress and physical exhaustion accounted for a high level of perceived conflict. One of them developed persistent sleep onset insomnia which resulted in chronic partial sleep deprivation, elevated ratings of daytime tiredness, and frequent deficits in behavioral alertness. Two team members did not manifest psychological distress over the entire period of confinement. Again, such psychological analyses with subjective data from the Beck depression inventory, conflict questionnaire, profile of moods assessment, psychomotor vigilance test, and ethological analyses together with objective data from daily life observations, combine to show that the group organization compensates for differences in individual reactions.

The behavioral adaptive strategy as a response to a high-stress environment would be a high level of behavioral stability. The Tara drift and Mars-500 experiment present similar temporal organizations but different spatial organizations of the isolated and confined team. On the one hand, these missions are of very long duration as they are beyond 500 days. Thus, long-term missions would have an impact on the way a team manages the collective time.

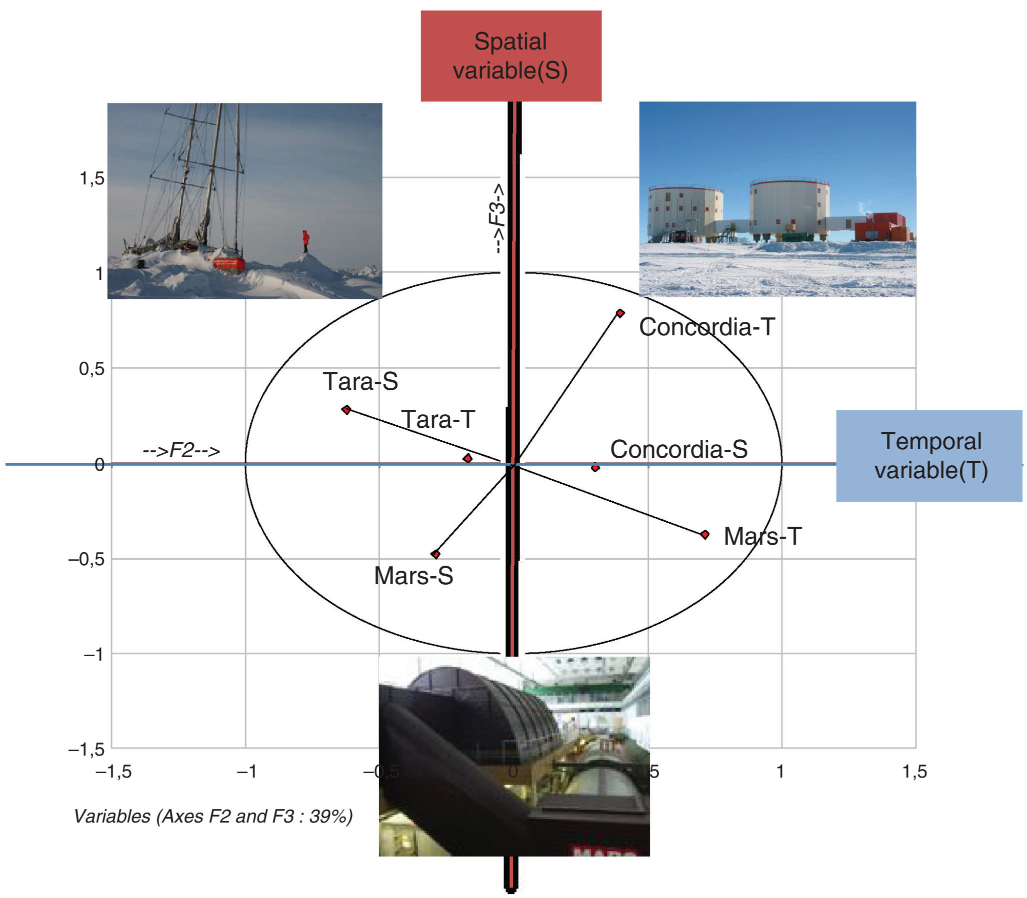

Figure 10. Principal component analysis (PCA) between the Concordia stay, Tara drift, and Mars-500 experiment based on the spatial indicators (changes of place) and the temporal indicators (meal durations) observed over time.

On the other hand, during the Tara drift the team is very isolated while during the Mars-500 experiment the team is very confined. In our observations, we found that these pronounced environmental conditions do generate different behaviors. Isolation impacts the way a team occupies the collective places by frequent changes, while confinement generates stereotypies by constant placing throughout the mission.

Globally, isolated and confined teams in a wide range of missions (polar expeditions, space flights, submarine operations) or experiments (campaigns in confinement chambers) follow similar rules by seeking the optimal way to equilibrate mood variations and behavioral changes over extended time periods. It concerns personal profiles and social context whatever the environmental properties are (reduced space, closed habitat, weightlessness, dangerous tasks, etc.). The day-to-day management of time and space could be common social rules. In any case, the observed behavioral changes over time indicate positive strategies. The main one is that the team member found in his or her simple difference with the other members the ways to express or to exchange the negative physiological effects (lack of sun during polar night, lack of mobility within closed habitat) and psychological effects (remote period from both the first day and the last day of the mission, separation of team) in synergy with prolonged effects (Tafforin, 2013a). This seems to be reinforced when the group organization implies differences in gender, nationality, and function as argued in previous studies of ICEs (Tafforin, 2013b). In this way, our results confirm the rules governing self-organized systems based on the heterogeneity of their own elements stated in the introduction.

In additional studies for future exploration missions, extended and new data analysis should be implemented in a dynamic view from video recordings. The ethological observations have to improve on motor indicators such as postural attitudes, gaze direction, and facial expressions, in order to complete information about the quality of individual strategies linked to personality traits and of inter-individual strategies linked to group characteristics. Monitoring of facial stress, for instance, was proposed in recent space flight applications (Dinges, Venkataraman, McGlinchey, & Metaxas, 2007). Social, temporal, spatial, and motor indicators could be used for evaluation and selection of space crews and polar crews in addition to psychological test batteries (Grant et al., 2007) as objective behavioral observations in response to subjective health complaints. From social and organizational psychology perspectives, interpersonal and group processes in long-term space flight crews refer to a social relation model from cultural heterogeneity and gender composition issues, leading to the selection for teams (Dion, 2004). Selection and training of polar teams, space teams, and interplanetary teams would consider the diversity of their elements in a positive way that defines a salutogenic basis. Ethological applications to ICEs reinforce these new perspectives to achieve the best equilibrium between the team members, leading to a better team performance. Scenarios of future missions in extreme conditions, particularly concerned with interplanetary explorations, would take into account these perspectives in monitoring isolated and confined teams. Of course, the gravity factor (Chappell & Klaus, 2013) is not simulated in ICEs and requires further study. When team members go outside in isolation during the Concordia stay and Tara drift or when team members walk inside the Martian confinement module, they only mimic extravehicular activities.

To conclude, the data presented in our study are descriptive and thus allowed us to objectively answer the primary question as to how a team adapts to a synergy of environmental factors exacerbated with time. The results support the whole hypothesis that the individual characteristics, the gender characteristics, and the cultural characteristics are heterogeneity elements that contribute to the evolving rules of isolated and confined teams with reference to group cohesion and the success of missions. The differences observed among the environments have helped to differentiate factors of isolation and confinement for possible applications on the ground. The observed associations have also helped to provide behavioral indicators in scenarios of extended time periods for future applications in interplanetary flight.

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